Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L4	2611	438/22,46,47,93,104.ccls.	US-PGPUB; USPAT	OR	ON	2005/09/22 09:11
L5	1911	4 and @ad<"20030414"	US-PGPUB; USPAT	OR	ON	2005/09/22 09:11
L6	3012	257/98,103.ccls.	US-PGPUB; USPAT	OR	ON	2005/09/22 09:11
L7	2306	6 and @ad<"20030414"	US-PGPUB; USPAT	OR	ON	2005/09/22 09:11
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TITLE: Opto-electronic integrated circuit

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Abstract Text - ABTX (1):
An optical electronic integrated circuit comprises: a silicon substrate; an electronic circuit formed in the silicon substrate and processing an electric signal; a **ZnO** film formed on at least portion of the silicon substrate; and an optical circuit electrically connected to the electronic circuit. The optical circuit includes at least one GaN-based semiconductor compound layer which is provided on the **ZnO** film, and the GaN-based compound semiconductor layer either receives or emits an optical signal.

Brief Summary Text - BSTX (13):
The OEIC comprises a silicon substrate; an electronic circuit formed in the silicon substrate and processing an electric signal; a **ZnO** film formed on at least portion of the silicon substrate; and an optical circuit electrically connected to the electronic circuit. The optical circuit includes at least one GaN-based semiconductor compound layer which is provided on the **ZnO** film and the GaN-based semiconductor compound layer either receives or emits an optical signal.

Brief Summary Text - BSTX (15):
The OEIC may further comprise an optical waveguide which is made of **ZnO** and optically connected to the optical circuit. Alternatively, the OEIC may further comprise a SiO.sub.2 film between the **silicon substrate and the ZnO** film while the **ZnO** film is optically connected to the optical circuit so as to act as an optical waveguide.

Brief Summary Text - BSTX (17):
According to the present invention, since a **ZnO** film is formed to serve as a buffer layer, the GaN layer formed on the buffer layer has fewer misfit dislocations, thereby obtaining a good crystallinity.

Brief Summary Text - BSTX (18):
Further, since the **ZnO** film serving as a buffer layer may be formed at a

relatively low temperature with a method such as sputtering, it inhibits bad influences caused by high temperature and possibly brought to the metal wires of the electronic circuit section of an OEIC. Moreover, since the metal wire section is covered by the **ZnO** film, the metal wires may be protected from direct exposure to high temperature during the process for forming the GaN layer, thereby effectively inhibiting the above-mentioned bad influence. At this time, since an ECR-MBE method is used to form the GaN layer, the GaN layer may be formed at a relatively low temperature, thereby further inhibiting a possible bad influence to the metal wire section.

Detailed Description Text - DETX (2):
The inventors of the present invention have conducted active research and have found that a **ZnO** layer can be suitably used as a buffer layer between a semiconductor compound layer and a silicon substrate or silicon layer.

Detailed Description Text - DETX (3):
A **ZnO** film (or layer) formed on a silicon substrate is usually orientated in a direction of axis c and the difference of the lattice constants between the **ZnO** film on the silicon substrate and the GaN film is only 2%. Therefore, it is possible to inhibit the misfit dislocation which is otherwise caused due to the lattice mismatch, making it possible to form a semiconductor compound having fewer dislocations and good film quality.

Detailed Description Text - DETX (4):
The semiconductor compound layer used in the present invention is preferably made of a III-V semiconductor compound, and more specifically, made of Ga.sub.1-x In.sub.x N, Ga.sub.1-x Al.sub.x N, Ga.sub.1-x B.sub.x N or mixed crystal thereof, i.e., GaN-based materials. These materials are suitable for a light emitting/receiving layer or an active layer for laser devices. Differences of the lattice constant between these materials and the **ZnO** film on the silicon substrate are so small that the semiconductor compound layers of these material formed on the **ZnO** film include less dislocations. In addition, these materials are not likely to degrade in light emitting/receiving characteristics regardless of existence of a small number of dislocations. Therefore, these semiconductor compounds can be suitably used to form an OEIC required to emit or receive light stably.

Detailed Description Text - DETX (5):
Further, another advantage which may be obtained by using the **ZnO** film is that the **ZnO** film can be formed at a relatively low temperature (at most 300.degree. C.) with the use of a method such as sputtering. In an OEIC, the electronic circuit section and the optical circuit section are formed

respectively with the use of different materials. This causes various problems due to different conditions for forming these sections. In particular, since the process of high temperature treatment is necessary for growing a semiconductor compound serving as a light emitting/receiving layer, metallization or metal wiring in the electronic circuit section is degraded by the high temperature treatment. One of the most important advantages obtainable in the present invention is that a buffer layer of **ZnO** may be formed at a temperature of 300.degree. C. or lower, which temperature is low enough so that there will be almost no bad influence to the metallization. Further, since the metallization is covered by the **ZnO** film during the process of high temperature treatment for growing the GaN layer, the metallization may avoid being directly exposed to the high temperature. In this way, since the **ZnO** film can act as a passivation film during the high temperature treatment, it is possible to inhibit possible bad influences on the metallization. According to the results of our experiments, it has been confirmed that when the **ZnO** film is formed so as to cover the metallization, and when the film formation temperature for forming the light emitting/receiving layer is kept at 800.degree. C. or lower, the bad influence on the metallization may be controlled within an allowable range. In the case where a polyimide material or the like is interposed as a protection layer between the **ZnO** film and the metallization, it is possible to further inhibit some bad influence to the metal wires, although adding such protection layer will cause the manufacturing process to become complex to some extent.

Detailed Description Text - DETX (7):

The above-explained **ZnO** film may be also used as an optical waveguide in the OEIC. This simplifies the structure of the OEIC. Further, since the optical signal may be transmitted without using an optical fiber, it is not necessary to install an optical fiber to the OEIC, thereby also simplifying a manufacturing process of the OEIC. A SiO.sub.2 layer having a lower refractive index than **ZnO** may be interposed between the **silicon substrate and a ZnO** film serving as a optical waveguide way.

Detailed Description Text - DETX (10):

FIG. 1 is a partial sectional view showing the structure an OEIC according to the first embodiment. As shown in FIG. 1, a **ZnO** film 2 is provided on a silicon substrate 1 and a GaN layer 3 is further provided on the **ZnO** film 2. The **ZnO** film 2 serves as a buffer layer helping to form the GaN layer 3 thereon. The GaN layer 3 generally represents a semiconductor compound layer which can emit or receive light. The structure of the OEIC shown in FIG. 1 is formed by the following processes.

Detailed Description Text - DETX (12):

Then, a **ZnO** film having a thickness of about 3 .mu.m is formed on the silicon substrate 1 with the use of a method such as RF magnetron sputtering. The **ZnO** film 2 is a polycrystal film orientated in a direction of axis c and serves to provide a function as a buffer layer for forming the GaN layer 3. Any thickness which performs that function can be employed. During the formation of the **ZnO** film 2 by a RF magnetron sputtering method, the desired film is formed while the silicon substrate is being heated. The silicon substrate 1 can be heated at a temperature of about 300.degree. C. at most, while the silicon substrate 1 is typically kept at a temperature of about 200.degree. C.

Detailed Description Text - DETX (13):

After the **ZnO** film 2 is formed in the above manner, the GaN layer 3 is formed on the **ZnO** film 2. The GaN layer 3 may be formed with the use of an ECR-MBE method. In more detail, ECR-MBE apparatus (not shown) including a plasma formation area and a film formation area is used to induce an electronic cyclotron resonance (ECR) phenomenon in the plasma formation area, thereby producing a plasma of nitrogen gas. Then, the plasma is supplied to the film formation area, and is caused to react with Ga metal supplied from Knudsen cells provided in the same film formation area, so as to form the desired GaN layer 3 on the **ZnO** film 2 in the film formation area. When the GaN layer 3 is formed with the use of the ECR-MBE method, since the raw material gas has already been in its highly energized state because of an ECR plasma condition in which it is in, it is sure to exactly form the GaN layer 3 even if the temperature of the substrate is not increased any further. In more detail, if the temperature of the silicon substrate is set at about 700.degree. C., the GaN layer 3 is formed without any difficulty. In this embodiment, the GaN layer 3 was formed at the substrate temperature of 720.degree. C.

Detailed Description Text - DETX (16):

FIG. 2 is a cross sectional view showing an OEIC according to the present embodiment. A photodiode is formed as an optical circuit comprising a light emitting/receiving layer on a **ZnO** film 12 which is provided on a single-crystal silicon substrate 11. A field effect transistor (MOSFET) 16 is formed as an electronic circuit on the same substrate 11. The photodiode is electrically connected to the MOSFET 16 through wiring 5. The photodiode 15 and the MOSFET 16 may be electrically connected by metallization (not shown) formed on the silicon substrate 11.

Detailed Description Text - DETX (18):

In the photodiode 15, an n-type GaN layer 13a is formed on the **ZnO** film 12

and a p-type GaN layer 13b is formed on the n-type GaN layer 13a so as to form a p-n junction. An n-type electrode 14a and a p-type electrode 14b are respectively provided on the n-type GaN layer 13a and the p-type GaN layer 13b so as to form an ohmic junction, respectively. The n-type GaN layer 13a and the p-type GaN layer 13b act as a light receiving layer and light entering the p-type GaN layer 13b generates carriers to cause a potential difference between the n-type electrode 14a and the p-type electrode 14b, thereby converting the light signal into an electric signal. The converted electric signal is fed to the MOSFET 16 as a control signal of the MOSFET 16.

Detailed Description Text - DETX (20):
Next, the same method discussed in the first embodiment is used to form the **ZnO** film 12, the n-type GaN layer 13a and the p-type GaN layer 13b except that the n-type GaN layer 13a and p-type GaN layer 13b are doped with impurities such as Si and Mg so as to form respective conductivity types. At the time, it is important to form the **ZnO** film 12 on the silicon substrate 11 at least so as to cover the MOSFET 16 as indicated by dotted line 12a. After that, a process such as reactive ion etching (RIE) is used to remove unwanted portions of the p-type GaN layer 13b, the n-type GaN layer 13a and the **ZnO** film 12. Although FIG. 2 shows that the MOSFET 16 is exposed by removing a portion 12a of the **ZnO** film 12, the portion 12a may not be removed. Further, the n-electrode 14a and the p-type electrode 14b are formed on the n-type GaN layer 13a and the p-type GaN layer 13b, respectively, thereby forming a photodiode 15. In this way is formed an OEIC capable of converting an external optical signal into an electric signal by virtue of the photodiode 15, and controlling the operation of the MOSFET 16 by virtue of the electric signal.

Detailed Description Text - DETX (21):
According to this structure, when the GaN layers 13a and 13b are formed under a condition of a high temperature, it may be ensured that various metal wires of the MOSFET section 16 serving as an electronic circuit section are protected by the **ZnO** film 12, so that these metal wires avoid being directly exposed to high temperature, therefore making it possible to inhibit deterioration in the operation performance of the MOSFET section 16, and thus properly maintaining the desired operation performance of an OEIC.

Detailed Description Text - DETX (25):
The OEIC according to the third embodiment of the present invention includes a laser section 25, a optical waveguide 32 and a MOSFET 26 on a single silicon substrate 21. The laser section 25 and the optical waveguide 32 are formed on or over a **ZnO** film 22 which is provided on the silicon substrate 21.

Detailed Description Text - DETX (27):

The laser 25 comprises an n-type GaN cladding layer 23a, a p-type GaN active layer 23b and a p-type GaN cladding layer 23c. These layers 23a, 23b and 23c are provided on the **ZnO** film 22 so that the p-type GaN active layer 23b is interposed between the n-type GaN cladding layer and the p-type GaN cladding layer 23c. An n-type electrode 24a and an p-type electrode 24b are provided on the n-type GaN cladding layer 23a and the p-type GaN cladding layer 23c, respectively.

Detailed Description Text - DETX (28):

The optical waveguide 32 is made of **ZnO** and provided on a SiO.sub.2 film 31 which is formed on the **ZnO** film 22. The optical waveguide 32 covers the side face of the p-type active layer 23b and the peripheral side regions of the junctions between the p-type GaN cladding layer 23c and the p-type GaN active layer 23b and between the n-type GaN cladding layer 23a and the p-type GaN active layer 23b so that the optical waveguide 32 is optically connected to the laser 25. Since the SiO.sub.2 film 31 has a refractive index smaller than the optical waveguide 32, a laser beam emitted from the laser 25 is effectively confined in the optical waveguide 31.

Detailed Description Text - DETX (30):

Since the optical waveguide 32 can be formed using the same material of the **ZnO** film 22, it is possible to simplify the manufacturing formation process. Further, since an optical signal may be transmitted without using an optical fiber, one can dispense with the troublesome installing operation for installing an optical fiber, thereby further simplifying the manufacturing process for manufacturing an OEIC.

Detailed Description Text - DETX (31):

In the present embodiment, the SiO.sub.2 layer 31 is formed beneath the optical waveguide 32 as a cladding layer of the optical waveguide 32 since SiO.sub.2 is a very common material to the silicon semiconductor devices and the manufacturing process can be simplified by using SiO.sub.2. However, it is possible to employ a film made of another material as long as the material has a refractive index smaller than the **ZnO**.

Detailed Description Text - DETX (35):

An OEIC according to the fourth embodiment of the present invention is formed in a manner such that on the silicon substrate layer 41 there are formed a light emitting diode 45 and a photodiode 53 each serving as a light emitting/receiving layer, an optical waveguide 52 formed of a **ZnO** material serving as an optical circuit section, and a MOSFET 46 serving as an electronic

circuit section. By adjusting the voltage applied to a gate electrode 48 of the MOSFET 46, it is sure to form an OEIC capable of controlling a light emission of a light emitting diode 45.

Detailed Description Text - DETX (36):
FIG. 4 is a cross sectional view showing an OEIC according to the present embodiment. Since the structure of MOSFET 26 of the fourth embodiment is just the same as that of the second embodiment, a description thereof is omitted here. As shown in FIG. 3, MOSFET 46 is formed in a silicon substrate 41 and a **ZnO** film 42 is formed on the surface of the silicon substrate 41 so as to cover the MOSFET 46. A light emitting diode 45 having an n-type GaN layer 43a and a p-type GaN layer 43b is formed on the **ZnO** film 42. An n-type electrode 44a and a p-type electrode 44b is electrically connected to the n-type GaN layer 43a and the p-type GaN layer 43b, respectively.

Detailed Description Text - DETX (37):
A SiO.sub.2 film 51 is formed on the **ZnO** film 42 and the light emitting diode 45 so as to cover the light emitting diode 45. A though hole exposing a portion of a surface of the p-type GaN layer 43b is provided in the SiO.sub.2 film 51 and an optical waveguide layer 52 is formed in the through hole so as to be optically connected to the light emitting diode 45. A photodiode 53 is formed on the optical waveguide 52 so as to receive a optical signal emitted from the light emitting diode 53. An electronic element 54 such as an inductor is also provided on the SiO.sub.2 film 51.

Detailed Description Text - DETX (38):
According this structure, the optical waveguide 52 can successfully confine the optical signal transmitting in the optical waveguide 52 by providing a SiO.sub.2 film 51 having a refractive index smaller than the **ZnO** around the optical waveguide 52.

Detailed Description Text - DETX (42):
The OEIC according to the fifth embodiment of the present invention comprises a silicon substrate 61, a MOSFET 76 formed in the silicon substrate, a light emitting diode 65 and a **ZnO** film 66 which also acts as an optical waveguide and is provided between the silicon substrate 61 and the light emitting diode 65. A SiO.sub.2 layer 67 is formed on the silicon substrate 67 so as to cover the MOSFET 76 and the **ZnO** film 66 is formed on the SiO.sub.2 layer 67. The light emitting diode 65 is formed on the **ZnO** film 66 so as to be optically connected with the **ZnO** film 66.

Detailed Description Text - DETX (44):

According to this structure, since the SiO_2 film 67 has refractive index smaller than **ZnO**, it is possible to confine the optical signal in the **ZnO** film 66 so as to act as an optical waveguide. Accordingly, the **ZnO** film 66 can work as both a buffer layer for forming a GaN layer and an optical waveguide. This greatly simplifies the production steps as it is not necessary to form an optical waveguide separately.

Detailed Description Text - DETX (45):

Although in the above-explained OEIC, the SiO_2 film 67 is employed between the **ZnO** film 66 and the silicon substrate 61, other films having a refractive index smaller than **ZnO** may be used. Further, another SiO_2 film or another film having a refractive index smaller than **ZnO** may be formed on the top surface of the **ZnO** film 66 so as to increase the transmission efficiency of the **ZnO** film 66 as an optical waveguide.

Claims Text - CLTX (1):

1. A method of forming an optical electronic integrated circuit, comprising the steps of: providing a silicon substrate including an electronic circuit for processing an electric signal; forming a **ZnO** layer on at least a portion of the silicon substrate; and forming an optical circuit electrically connected to the electronic circuit and comprising at least one GaN-based semiconductor compound layer on the **ZnO** layer, wherein the GaN-based semiconductor compound layer either receives or emits an optical signal; and wherein the GaN-based semiconductor compound layer is formed at a temperature of 800.degree. C. or lower; and further comprising the step of forming an additional layer of **ZnO** optically connected to the optical circuit and dimensioned so as to function as an optical waveguide.

Claims Text - CLTX (2):

2. A method of forming an optical electronic integrated circuit according to claim 1, further comprising the step of forming a SiO_2 layer between the **silicon substrate and the ZnO** layer, and wherein the **ZnO** film is optically connected to the optical circuit so as to act as an optical waveguide.

Claims Text - CLTX (3):

3. A method of forming an optical electronic integrated circuit according to claim 2, wherein the silicon substrate includes a MOSFET and wherein the **ZnO** layer is initially formed so as to cover that portion of the silicon substrate which includes the MOSFET and is thereafter eliminated from said portion.

Claims Text - CLTX (4):

4. A method of forming an optical electronic integrated circuit according

to claim 2, wherein the silicon substrate includes a MOSFET and wherein the **ZnO** layer is initially formed so as to cover that portion of the silicon substrate which includes the MOSFET and is thereafter eliminated from said portion.

Claims Text - CLTX (9):
9. A method according to claim 1, wherein the **ZnO** layer does not cover the electronic circuit.

Claims Text - CLTX (10):
10. A method according to claim 1, wherein the **ZnO** layer covers the electronic circuit.

Claims Text - CLTX (11):
11. A method of forming an optical electronic integrated circuit, comprising the steps of: providing a silicon substrate including an electronic circuit for processing an electric signal; forming a **ZnO** layer on at least a portion of the silicon substrate; and forming an optical circuit electrically connected to the electronic circuit and comprising at least one GaN-based semiconductor compound layer on the **ZnO** layer, wherein the GaN-based semiconductor compound layer either receives or emits an optical signal; and further comprising the step of forming an additional layer of **ZnO** optically connected to the optical circuit and dimensioned so as to function as an optical waveguide.

Claims Text - CLTX (15):
15. A method according to claim 11, wherein the **ZnO** layer does not cover the electronic circuit.

Claims Text - CLTX (16):
16. A method according to claim 11, wherein the **ZnO** layer covers the electronic circuit.

Claims Text - CLTX (17):
17. A method of forming an optical electronic integrated circuit according to claim 11, further comprising the step of forming a SiO.sub.2 layer between the **silicon substrate and the ZnO** layer, and wherein the **ZnO** film is optically connected to the optical circuit so as to act as an optical waveguide.

Claims Text - CLTX (18):
18. A method of forming an optical electronic integrated circuit, comprising the steps of: providing a silicon substrate including an electronic circuit for processing an electric signal; forming a **ZnO** layer on at least a

portion of the silicon substrate; and forming an optical circuit electrically connected to the electronic circuit and comprising at least one GaN-based semiconductor compound layer on the **ZnO** layer, wherein the GaN-based semiconductor compound layer either receives or emits an optical signal; and wherein the GaN-based semiconductor compound layer is formed by the ECR-MBE method; and further comprising the step of forming an additional layer of **ZnO** optically connected to the optical circuit and dimensioned so as to function as an optical waveguide.

Claims Text - CLTX (19):

19. A method of forming an optical electronic integrated circuit according to claim 18, further comprising the step of forming a SiO.sub.2 layer between the **silicon substrate and the ZnO** layer, and wherein the **ZnO** film is optically connected to the optical circuit so as to act as an optical waveguide.